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SEA-LEVEL AND HIGH-ALTITUDE PERFORMANCE OF EXPERIMENTAL PHOTOFLASH COMPOSITIONS

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PICATINNY ARSENAL
DOVER, N. J.

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OBJECT

To investigate the luminosity characteristics of selected fuels, oxidants, and additives as ingredients in high-altitude photoflash compositions.

SUMMARY

Calcium/magnesium and calcium/aluminum alloys are satisfactory substitutes for calcium metal powder as highly efficient fuels for high-altitude photoflash items. When tested under pressures simulating a 100,000-foot altitude, these alloys had much greater light output than at sea level. This phenomenon can also be obtained with compositions containing calcium salts which are oxidants (calcium nitrate, calcium perchlorate) or additives (calcium oxide or calcium fluoride).

Test results indicated that calcium—as a metal powder, alloy, or salt—is necessary for the production of superior high-altitude flashes.

The alkaline earth perchlorates were found to be better oxidants than the alkali metal perchlorates. Of the alkaline perchlorates evaluated (calcium, strontium, and barium), the calcium compound was optimum at both sea level and high altitude. Sodium perchlorate was optimum at high altitude among the alkali perchlorates investigated (sodium, potassium, and lithium).

Substituting alkaline earth perchlorates for their respective nitrates considerably improved light output at both sea level and high altitude. Substituting barium perchlorate for barium nitrate also improved the ignitability of the composition.

Of the high-energy fuels evaluated (aluminum, magnesium, zirconium, titanium, calcium, boron, and silicon), aluminum and magnesium were most efficient at sea level, while calcium was most efficient at 100,000 feet.

CONCLUSIONS[1]

a. At high altitudes, the ultimate performance of any specific fuel-oxidant mixture depends on the formation and energy content of discrete bands.

b. Whereas the conversion of chemical energy to heat energy is most important at sea level, the ability of a compound to emit radiation in discrete bands becomes the critical factor at high altitudes.

c. The type of spectra formed at high altitudes may be predicted by comparing the luminosity values obtained from each specific composition at high altitudes with like values obtained from the same composition at sea level.

d. Of the alkali perchlorates evaluated as oxidants at high altitude (sodium, potassium, lithium), sodium perchlorate was optimum.

[1]Conclusions a, b, and c are general assumptions based in part on information obtained by spectrographic analyses of selected flashes reported in Picatinny Arsenal Technical Report 2646, October 1959.

e. Of the alkaline perchlorates evaluated as oxidants at high altitude (calcium, strontium, barium), calcium perchlorate was optimum.

f. Of the alkaline earth nitrates evaluated at high altitude (calcium, strontium, barium), calcium nitrate was optimum.

g. Substituting alkaline perchlorates for their respective nitrates considerably improves the ignitability and light output of mixtures at both sea level and high altitude.

h. As a class, the alkaline earth perchlorates appear to be superior to the alkali metal perchlorates.

i. Of all the oxidants evaluated with aluminum as the sole fuel, only calcium perchlorate and calcium nitrate yielded more light at high altitude than at sea level. For the nitrate, the increase in light output at 100,000 feet was similar in magnitude to that obtained for compositions containing calcium metal and calcium alloy, indicating the formation of the same discrete-band-emitting species.

j. The phenomenon of increasing light output with increasing altitude obtained for compositions containing calcium metal, calcium alloys, calcium perchlorate, and calcium nitrate can also be obtained by adding inert calcium salts (calcium oxide and calcium fluoride) to a high-temperature-producing composition (aluminum/potassium perchlorate). Although the magnitude of the increase in total light was considerably less for the compositions containing calcium additive, these fast and high-peaking flashes are of considerable interest for future applications.

k. Of the high-energy fuels evaluated (aluminum, magnesium, zirconium, titanium, calcium, boron, and silicon), aluminum and magnesium were the most efficient at sea level, calcium at 100,000 feet.

l. In general but within limits, the trend is towards increasing light output of a specified fuel-oxidant mixture with increasing fuel content above the stoichiometric amount.

m. Calcium-magnesium alloy and calcium-aluminum alloy can be substituted for calcium metal powder without any significant loss of light output at either sea level or 100,000 feet.

n. The partial substitution of aluminum for calcium gives the fast time-to-peak-intensity characteristic of aluminum compositions while still maintaining the relatively-high-light-yield characteristic of calcium compositions.

INTRODUCTION

1. In an earlier report (Ref 1), the factors responsible for the formation of highly efficient flashes at high altitude

were discussed and their implications pointed out. In brief, it was found that the combustion of calcium metal powder under reduced pressure produces spectrally active calcium oxide molecules which emit intense bands in the visible region. It is also definitely known that the present photoflash mixtures of powdered fuel and oxidant can support a propagating flame only if the fuel-oxidant ratio is within certain defined limits. Since a considerable quantity of oxidant is required for propagation within these limits, a program was initiated to investigate oxidants which can be used as additional sources of discrete-band-emitting molecules.

2. In addition, because of difficulty in obtaining calcium metal powder in the 20-micron range, a study was initiated to evaluate readily obtainable calcium compounds such as calcium hydride, calcium/magnesium alloy, and calcium/aluminum alloy as replacements for calcium metal powder.

3. It should be emphasized that, since the flashes obtained were not examined spectroscopically, the program was inadequate from the standpoint of providing information on the reaction and emission processes occurring in the flashes. The importance of spectroscopy as an analytical tool in quantitatively determining the effects of altitude on the emission characteristics of flashes was confirmed by work with calcium reported in Picatinny Arsenal Technical Report 2645 (Ref 1). The information obtained also added considerably to the general understanding of flashes occurring at low pressures.

4. Though relatively little work was performed at Picatinny on the spectrographic examination of the flashes obtained in the present study, it was felt that the lack of such information should not delay the dissemination of the considerable amount of luminosity data that was accumulated. Therefore, this report does not develop any new theories or concepts regarding high-altitude flashes, but only relates as factually as possible the relative merits of individual ingredients which can be used in photoflash compositions.

RESULTS AND DISCUSSION

5. The results of the luminosity measurements are presented in Tables 1 through 14 (pp 13 through 26), in most cases as averages for 5-test-round groups. Data for cartridges which did not function properly was excluded from the averages.

Oxidants

6. As Table 1 (p 13) shows, binary compositions containing selected alkali metal perchlorates (potassium, sodium, and lithium) in combination with calcium metal powder did not show any significant differences in luminosity characteristics at sea level. The similarity of results was anticipated since a spectroscopic study of flashes (Ref 1) had revealed that the visible emission at sea level is essentially due to gray-body radiation.

7. In contrast to the sea-level results,

significant differences in the burning and light characteristics were obtained at 100,000 feet. In each group, the composition containing sodium perchlorate as the oxidant yielded the most light. Since the heat output per unit weight of composition was comparable for all of the oxidants evaluated, it would appear that the additional light from the sodium perchlorate compositions may have been due to discrete lines emitted by atomic sodium.

8. Both at sea level and at 100,000 feet, the time to peak intensity was considerably shorter for the stoichiometric compositions than for the fuel-rich compositions. For that matter, with the exception of a calcium/calcium nitrate composition (discussed later in the report), relatively low peak intensity and relatively long time to peak intensity appeared to be characteristic of the fuel-rich calcium compositions. Increasing the calcium-free metal content by the use of a higher-purity calcium powder substantially improved the light output per gram of composition.

9. As Table 2 (p 14) shows, trends similar to those discussed above for the calcium compositions were also found to exist for the aluminum compositions. At sea level, the composition containing lithium perchlorate emitted the most light per unit weight of composition and exhibited the highest peak light level. At the simulated 100,000-foot altitude, the composition containing sodium perchlorate was the most efficient, yielding the highest peak light and total light values. Although the light output was lower at 100,000 feet than at sea level for all three compositions, the reduction was less for the sodium perchlorate composition than for the lithium perchlorate and potassium perchlorate compositions. Assuming that the energy level of the continuum decreases comparably for all of these compositions, the smaller decrease in light output obtained for the sodium perchlorate composition may indicate sodium (D) line emission.

10. Another attempt to develop more efficient photoflash compositions was the use of representative alkaline earth perchlorates (calcium, barium, and strontium) as potential sources of discrete-band emitters and consequently more efficient oxidants. Luminosity characteristics of stoichiometric aluminum compositions containing these oxidants are compared in Table 3 (p 15) to those containing alkali metal perchlorates.

11. From the standpoint of total light output both at sea level and at the simulated 100,000-foot altitude, the alkaline earth metal perchlorates were superior to the alkali metal perchlorates as oxidants.

12. Attempts to correlate the light output of each group of oxidants with the position of its cations in the periodic table revealed a trend toward increasing efficiency with increasing stability of the compounds. This trend follows the order of Ca>Sr>Ba and Na>K. Of the alkaline earth perchlorates

evaluated, calcium perchlorate was optimum both at sea level and at 100,000 feet. At 100,000 feet, its composition yielded exceptionally high peak candlepower values accompanied by very short rise times. It was the only perchlorate evaluated whose composition emitted more light at 100,000 feet than at sea level.

13. However, the magnitude of the increase (22%) was considerably less than the 150% increase obtained with calcium metal powder and the 194% increase obtained with calcium nitrate (Table 4, p 16). When formulated in stoichiometric proportions, the calcium perchlorate composition yielded the most light per unit weight of composition both at sea level and at 100,000 feet. Comparing the efficiencies of the three compositions in terms of the quantity of calcium available for discrete-band-emitting molecules (CaO or CaCl) did not indicate any relationship between calcium content per se and light output.

14. However, for a specific system, as previously reported in Picatinny Arsenal Technical Report 2467 (Ref 1), increasing the calcium metal content from 40% to 85% produced a continuous increase in light output. These relationships indicate the possibility of more efficient formation and utilization of the discrete-band-emitting species by the calcium-containing oxidants.

15. The data also shows considerable improvement in light output for the calcium nitrate and calcium metal powder compositions when tested at 100,000 feet, but only slight improvement for the calcium perchlorate composition. Since it is definitely known that calcium metal powder emits radiation by both band and continuum at high altitude and by continuum only at sea level, the possibility exists that the consistent light output obtained up to 100,000 feet for calcium perchlorate may be due to discrete band emission at both high altitude and sea level. In all probability, the emitting species for the calcium perchlorate composition is CaCl while CaO is the emitter for calcium powder and calcium nitrate (Ref 2).

16. The results obtained are very significant in that they suggest the possibility of substituting unreactive calcium salts for the highly reactive calcium metal powder. It should be stressed that, although compositions containing calcium powder in large excess produce very efficient flashes at 100,000 feet, they peak at considerably lower candlepower values than calcium salt compositions containing aluminum powder as the fuel (Tables 4 and 6, pp 16 and 18).

17. In an attempt to develop a composition which would yield maximum efficiencies on a weight basis, calcium metal powder was evaluated in comparison with conventional oxidants such as potassium perchlorate, sodium perchlorate, sodium nitrate, barium nitrate, and calcium nitrate. All of the compositions were fuel rich, the magnitude of the excess of fuel over stoichiometric requirements ranging from 18% to 45% (Tables 5 and 6, pp 17 and 18). To properly evaluate

the contribution made by the oxidant to the luminosity characteristics of the composition, comparisons will be made only with compositions which contain a comparable excess of fuel. Since calcium has been evaluated almost exclusively with potassium perchlorate as oxidant, representative compositions from this system will be used chiefly as standards for comparison.

18. As Table 5 (p 17) shows, the use of sodium perchlorate (in an 80/20 calcium/sodium perchlorate mixture) instead of potassium perchlorate (in the 75/25 calcium/potassium perchlorate mix) did not significantly alter the luminosity characteristics at sea level. However, at 100,000 feet (Table 6, p 18) the light output showed considerable improvement when the sodium perchlorate composition was used. The partial substitution of sodium nitrate for sodium perchlorate (in an 80/10/10 calcium/sodium perchlorate/sodium nitrate) did not significantly affect the light output at either sea level or 100,000 feet. This result is of considerable interest since it suggests that the complete substitution of relatively nonhygroscopic sodium nitrate for hygroscopic sodium perchlorate may be feasible.

19. A comparison of the luminosity characteristics of the barium nitrate composition with those of two potassium perchlorate compositions (85/15 and 90/10 calcium/potassium perchlorate) show that potassium perchlorate is superior to barium nitrate as an oxidant at both sea level and 100,000 feet. The use of calcium nitrate (Table 6) in place of potassium perchlorate in a 90/10 calcium/potassium perchlorate composition gave comparable integral light values at 100,000 feet. The most important feature of these results is that, for the first time, a fuel-rich calcium binary composition has been found which yields a relatively high peak intensity and a fast time to peak intensity. The reason this calcium-calcium nitrate composition exhibited luminosity characteristics not previously associated with compositions containing a large excess of calcium is not presently understood.

20. Because of the promising results obtained for the calcium nitrate compositions (Tables 4 and 6, pp 16 and 18), additional alkaline earth nitrates were evaluated with atomized aluminum. As Table 7 (p 19) shows, the phenomenon of increasing light output with increasing altitude did not occur for either the barium nitrate composition or the strontium nitrate composition. Although the strontium nitrate composition yielded the most light per gram of composition at sea level, the light output dropped off radically at 100,000 feet. The barium nitrate composition was very difficult to ignite and, when ignited, yielded very little light. Since the literature (Ref 2) reports the existence of relatively intense strontium oxide bands, the low light output of the strontium nitrate composition is not presently understood. Again, the lack of spectrographic data places severe limitations on the analysis of the results.

21. As Table 8 (p 20) shows, the

substitution of perchlorates for the nitrates considerably improved the light output at both sea level and 100,000 feet. Thermal calculations indicate that the higher light values obtained for the perchlorate compositions may possibly be due to a higher heat output, which is reflected in the temperature of the flashes.

22. The relative light output of the oxidizing agents tested may be summarized as follows:

a. Perchlorates (Sea level and 100,000 feet) – Calcium>strontium>barium>sodium>lithium>potassium.

b. Nitrates (100,000 feet) – Calcium>strontium>barium.

c. Nitrates (Sea level) – Strontium>calcium>barium.

d. Oxidants (Sea level and 100,000 feet) – Perchlorates>nitrates.

Additives

23. The promise shown by calcium nitrate as an oxidant for high-altitude use initiated a study of inert calcium salts to be used as additives with a high-heat-producing (aluminum/potassium perchlorate) composition. To maintain a basis of comparison for the various compositions evaluated, all of these compositions were designed to contain approximately 14% by weight of fuel in excess of the stoichiometric quantity.

24. Two salts, calcium oxide and calcium fluoride, were selected on the basis of the large number of discrete bands reported for their respective products: calcium oxide (CaO) and calcium subfluoride (CaF). As Table 9 (p 21) shows, the trend at 100,000 feet was towards increasing light output with increasing calcium oxide or calcium fluoride content up to 20 percent by weight. At sea level, the addition of up to 20 percent by weight of calcium oxide or 9 percent by weight of calcium fluoride did not essentially reduce the efficiency of the binary aluminum/potassium perchlorate composition. These results are surprising in that the additives can be considered as being inert and therefore would not supply any energy to the flame.

25. Previous work with flashes (Ref 1) did not indicate any appreciable band formation at sea level, even though band-emitting species were present. Hence, a considerable reduction in light output was expected. The reason this reduction did not materialize is not presently understood. Of considerable interest are the high peak intensities obtained at 100,000 feet for the additive-containing compositions. From the standpoint of handling and storage, relatively nonhygroscopic calcium fluoride is far superior to such hygroscopic calcium salts as calcium nitrate and perchlorate.

Fuels

26. In an attempt to classify the conventional high-temperature-producing fuels in terms of luminosity characteristics, stoichiometric compositions containing the fuels, aluminum, magnesium, zirconium, titanium, calcium, boron, and

silicon in combination with potassium perchlorate were tested at sea level and at a simulated altitude of 100,000 feet (Table 10, p 22). With the exception of calcium, all of the fuels yielded an equal or smaller amount of light at 100,000 feet than at sea level. The difference between the amount of light emitted at sea level and the amount emitted at 100,000 feet for each composition is due to the types of spectra formed. A spectroscopic analysis of photoflashes (Ref 1) revealed that radiation is emitted chiefly by continuum at 100,000 feet.

27. The major limiting factors in the achievement of high temperatures, the boiling point and the extent of dissociation of the reaction products, are dependent on the existing pressures. It is obvious therefore that the final flash temperature is a function of the external pressure and consequently will decrease with increasing altitude. Although the larger flash areas obtained at 100,000 feet (Ref 1) compensate to some extent for the loss in light output due to lower flash temperatures, lower light values are obtained at higher altitudes, indicating that gray body radiation is the principal source of emission.

28. At sea level, the most efficient fuels were magnesium and aluminum, which yielded approximately 10,000 candleseconds per gram of fuel. The least efficient fuel was boron, which yielded 3500 candleseconds per gram. The luminosity characteristics of silicon could not be determined because it did not ignite. Of interest are the unusual luminosity characteristics exhibited by boron. The low-peak, long-time-to-peak, long-burning-duration, and low-light-output characteristics of the metal all differ substantially from data obtained for the other fuels. At 100,000 feet, the most efficient fuel was calcium and the least efficient fuels were magnesium and boron. Of considerable interest is the behavior of the magnesium flash at 100,000 feet. Whereas the flashes ($^1/_{10}$ max) for the aluminum, zirconium, and titanium compositions were respectively 22%, 57%, and 56% shorter at 100,000 feet than at sea level, the magnesium composition exhibited an extraordinary 93% reduction. This substantial increase in the rate of cooling from peak light to $^1/_{10}$ peak light level at 100,000 feet is not understood. It should be noted that the 93% reduction in the light output of the magnesium flash at 100,000 feet is comparable to the reduction obtained for magnesium flare compositions at 100,000 feet, indicating that there is some similarity in the combustion processes for the two systems.

29. To determine the existence of any trends in light output versus fuel content, each of the binary systems was evaluated with additional compositions containing an excess of fuel. The choice of 14% as the amount by which the fuel was made to exceed stoichiometric proportions has no special significance. As Tables, 11, 12, and 13 (pp 23, 24, and 25) show, the light output was in all instances was greater for the fuel-rich compositions than for the stoichiometric

compositions at both sea level and 100,000 feet.

30. At sea level, the increases in light output per unit weight of fuel ranged from a nominal 4% for titanium to a substantial 147% for zirconium. At 100,000 feet, the light output per unit weight of fuel was slightly lower for the fuel-rich aluminum and magnesium compositions than for the parallel stoichiometric compositions. The reverse was true for the zirconium, titanium, and calcium compositions. Again, calcium was the only fuel yielding considerably more light at 100,000 feet than at sea level. Titanium emitted slightly more light at 100,000 feet than at sea level. For spotting purposes, the high-peak and fast-time-to-peak characteristics exhibited by the fuel-rich zirconium composition are of considerable interest. Where differences between the duration ($^1/_{10}$ max) and total duration values are substantial, it is due to a relatively slow cooling rate from the $^1/_{10}$ max level to a light level too low to measure. The amount of light found in this "tail-off" area is usually a very small percentage of the total light.

Calcium-Containing Fuels

31. Substitution of calcium/aluminum alloy or calcium/magnesium alloy for calcium metal powder did not significantly alter the light output at either sea level or 100,000 feet (Table 14, p 26). However, the use of calcium hydride as a fuel gave very poor luminosity characteristics. These inordinately low values indicate non-calcium-type emission, especially at high altitudes. For purposes of comparison, the compositions were listed according to their free metal calcium content (calcium content capable of being oxidized to calcium oxide). Since calcium was found to be far superior to aluminum or magnesium as a fuel, it was believed that most of the light emitted by the alloys at 100,000 feet could be attributed to the available calcium. Therefore, the light output of each alloy should be related to the quantity of calcium available for reaction.

32. As Table 14 shows, a relationship does appear to exist between the calcium free metal content and light output for the calcium-magnesium alloy and calcium powders (80/20 compositions). However, the light output per gram of free metal calcium obtained for the calcium/aluminum alloy is exceptionally high, and does not reveal any relationship between calcium content per se and light output. The low calcium content of this alloy accompanied by high light values indicates emission by a molecular species other than, or in addition to, calcium oxide molecules. It should be noted that the luminosity characteristics of the alloys approach those of calcium metal and not of the aluminum or magnesium constitutents, indicating that calcium is the dominant fuel in determining the mechanism of the reaction. Examination of the data shows that luminosity values characteristic of calcium compositions also occur with the alloys (such as relatively low peak intensity, long time to peak intensity, long burning duration,

and increased light output at 100,000 feet). On the other hand, the addition of aluminum to a binary calcium/oxidant composition gave results that approach those characteristics of aluminum compositions, such as high peak, fast time to peak, and short duration (Table 15, p 27).

33. It should be pointed out that, since the total light output is essentially a function of the peak intensity, rate of cooling, and burning duration, the evaluation of various fuels and oxidants in terms of their light output (integral light) may be misleading. To adequately evaluate two or more compositions whose burning durations differ substantially, the average intensity (integral light/duration) or light level should also be compared. As Table 14 (p 26) shows, calcium compositions exhibited the highest intensities at both sea level and 100,000 feet. Data on the sensitivity to impact and friction of most of the compositions evaluated is shown in Table 16 (p 28).

EXPERIMENTAL PROCEDURES

Handling

34. In general, the fuels—calcium metal powder, calcium hydride, calcium/aluminum alloy, and calcium/magnesium alloy— and the salts—lithium perchlorate, sodium perchlorate, calcium perchlorate, strontium perchlorate, barium perchlorate, calcium nitrate, and calcium oxide—whether used alone or in compositions must be stored in airtight containers to protect them from atmospheric moisture. Long exposure to ordinary air or short exposure to humid air should be avoided for the following reasons: (a) the subsequent reduction in free metal content of the fuels will have an adverse effect on the light output of their respective compositions; (b) under conditions where the heat generated by the reaction of moisture with one of the metal powders is not dissipated rapidly enough, ignition of the composition may occur; and (c) the presence of moisture in the oxidant will adversely effect the light output of the composition.

35. Because of the rapidity with which the cartridges were loaded and sealed with full charges of composition, the moisture sensitive ingredients were exposed to the atmosphere for a period of only 15 minutes. Thus, a fairly high relative humidity of 75% has been established as a safe upper limit for both the blending and the loading operations.

36. The sensitivity to friction and impact of most of the compositions evaluated is shown in Table 16. From the standpoint of future use, the important fuels aluminum and calcium show relatively low friction sensitivity, as indicated by the no-action results obtained in the fibre shoe test. However, calcium does show high sensitivity to impact.

[1] Since the hazard of ignition from the build-up of electricity in a dry atmosphere is greater than the hazard of ignition from a calcium-moisture reaction in a humid atmosphere, all current work is being conducted under relative humidities of from 40% to 75%, and the cartridges are being loaded by remote control.

Blending and Loading

37. All of the compositions were dry blended in accordance with Sequence of Operations P.A.C.U. No. 5. Loading was performed by remote control according to Sequence of Operations T1034–5–48. Each Daisy or modified M112 cartridge contained 250 mg of lead azide and 35 mg of lead styphnate in the relay charge and a delay charge consisting of 800 mg of 90/10 barium chromate/boron. To obtain an airtight seal, the threads and/or crimped portion of each charge case were coated with synthetic rubber adhesive.

Testing

38. The cartridges were tested in a high-altitude tank which can be evacuated to 8-mm pressure, simulating an altitude of 100,000 feet. Each cartridge was suspended in a horizontal position at the center of the 15-foot-diameter portion of the tank by taping them to a ½-inch-diameter vertical steel rod. The end of the cartridge containing the delay-relay assembly was faced away (180 degrees) from the photocell. A photocell-oscilloscope combination was used to pick up the light emitted. Initiation of the delay composition was by 90/10 barium chromate/boron loaded in an M1A1 squib housing.

Materials Used

Fuels

a. Calcium metal powder, 85% and 92% free metal content, average particle diameter, 23 microns, Ethyl Corporation.

b. Calcium hydride, 91.3% purity, average particle diameter, 13 microns, Metal Hydrides Co.

c. Calcium-magnesium alloy (73% calcium, 22% magnesium), average particle diameter, 35 microns, Dow Chemical Co.

d. Calcium-aluminum alloy (50% calcium, 38% aluminum), average particle diameter, 19 microns, Valley Metallurgical Co.

e. Atomized aluminum, average particle diameter, 15 microns, Metals Disintegrating Co.

f. Boron, average particle diameter, 1 micron, American Potash Co.

g. Magnesium, average particle diameter, 20 microns, Ruffert Chemical Co.

h. Silicon, average particle diameter, 2.2 microns, Arner Co.

i. Titanium, average particle diameter, 6.4 microns, Hydrimet Co.

j. Zirconium, average particle diameter, 26 microns, Foote Mineral Co.

Oxidants and Additives

a. Barium nitrate, average particle diameter, 20 microns, Baker Co.

b. Barium perchlorate, average particle diameter, 22 microns, G. Smith Chemical Co.

c. Calcium fluoride, average particle size, 3.5 microns, Baker Chemical Co.

d. Calcium nitrate, average particle diameter, 24 microns, Mallinckrodt Chemical Co.

e. Calcium oxide, average particle diameter, 13 microns, Merck Chemical Co.

f. Calcium perchlorate, average particle diameter, 16 microns, G. Smith Chemical Co.

g. Lithium perchlorate, average particle diameter, 22 microns, American Potash and Chemical Co.

h. Potassium perchlorate, average particle diameter, 24 microns, Sobin Chemical Co.

i. Strontium nitrate, average particle diameter, 20 microns, Davies Nitrate Chemical Co.

j. Strontium perchlorate, average particle diameter, 20 microns, G. Smith Chemical Co.

k. Sodium nitrate, average particle diameter, 20 microns, Davies Nitrate Chemical Co.

l. Sodium perchlorate, average particle diameter, 20 microns, G. Smith Chemical Co.

Metal Parts

a. Daisy charge case, cover case, and relay cup, Drawing P–88928 dated 5 Sept 1956

b. Modified M112 charge case, Drawing 78–2–535 dated 5 June 1951 with the exception that the length of cartridge was reduced to 1.72 inches.

REFERENCES

1. Lopatin, Seymour, *High Altitude Flash Characteristics of Calcium/Potassium Perchlorate and Standard Photoflash Compositions*, Picatinny Arsenal Technical Report 2646, October 1959

2. Pearse and Gaydon, *The Identification of Molecular Spectra*, John Wiley & Sons, Inc, 1941

TABLE 1

Luminosity Characteristics of Binary Mixtures of Calcium and Potassium Perchlorate, Sodium Perchlorate, or Lithium Perchlorate[a]

Group[b] No.	Composition, % Calcium	Potassium Perchlorate	Sodium Perchlorate	Lithium Perchlorate	Composition Weight, g	Peak Intensity, 10^3 candles	Time to Peak, msec	Integral Light, 10^3 candlesec	Duration ($^1/_{10}$ max), msec	Efficiency, 10^3 candlesec/g
					Sea Level					
1	58	42			14.0	8	1.8	60	16	4
	60		40		13.6			60		4
2	80	20			11.7	9	4.4	101	19	9
	80		20		13.3	10	4.9	108	18	8
3	80				15.0	11	4.0	136	21	9
	80		20		15.9	12	4.3	144	21	9
	80			20	15.5	13	3.4	158	22	10
					100,000 Feet					
1	58	42			14.0	16	0.6	152	23	11
	60		40		13.6	18	0.6	214	36	16
2	80	20			11.7	9	14.8	271	47	23
	80		20		13.3	12	16.1	364	48	27
3	80	20			15.0	12	15.8	449	45	30
	80		20		15.9	17	14.8	572	57	36
	80			20	15.5	16	10.2	465	53	30

[a] Test vehicle, Daisy cartridge, magnesium case, with 0.075-inch-thick walls.

[b] Group 1 compositions: stoichiometric for 85% free metal calcium.

Group 2 compositions: excess fuel, 85% free metal calcium.

Group 3 compositions: excess fuel, 92% free metal calcium.

TABLE 2

Luminosity Characteristics of Photoflash Compositions Containing Alkali Metal Perchlorates as Oxidants and Aluminum as Fuel[a]

Percent Oxidant[b]	Weight of Composition, g	Peak, 10^6 candles	Time to Peak, msec	Integral Light 10^3 candlesec		Duration, msec		Efficiency, 10^3 candlesec/g	
				$^1/_{10}$ max	Total	$^1/_{10}$ max	Total	$^1/_{10}$ max	Total
Sea Level									
54% Lithium perchlorate	47.5	55	1.8	380	396	14	22	8.0	8.4
57% Sodium perchlorate	32.5	35	1.3	184	227	13	23	5.7	7.0
61% Potassium perchlorate	42.0	41	1.7	226	246	11	16	5.4	5.9
100,000 Feet									
54% Lithium perchlorate	47.5	41	1.0	161	182	13	25	3.4	3.8
57% Sodium perchlorate	32.5	54	0.9	137	173	10	29	4.2	5.3
61% Potassium perchlorate	42.0	49	1.2	115	139	8	16	2.7	3.3

[a] Test vehicle, modified M112 charge case, 1.72 inches long.

[b] Remainder of composition consisted of aluminum powder, the quantity being 14% in excess of the stoichiometric amount.

TABLE 3

Luminosity Characteristics of Stoichiometric Perchlorate/Aluminum Compositions[a]

Percent Oxidant[b]	Weight of Composition, g	Peak, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec		Duration, msec		Efficiency, 10^3 candlesec/g	
				$^1/_{10}$ max	Total	$^1/_{10}$ max	Total	$^1/_{10}$ max	Total
Sea Level									
63% Sodium perchlorate	33	31	0.9	128	140	10	21	3.9	4.2
66% Potassium perchlorate	42	41	1.2	147	160	9	14	3.5	3.8
62% Calcium perchlorate	33.7	54	0.6	291	314	12	24	8.6	9.3
66% Strontium perchlorate	42	64	1.6	327	343	10	19	7.8	8.2
70% Barium perchlorate	43	57	1.2	251	265	10	19	5.8	6.2
100,000 Feet									
63% Sodium perchlorate	33	52	0.7	86	133	7	31	3.0	4.0
56% Potassium perchlorate	42	49	1.3	103	125	7	14	2.5	3.0
62% Calcium perchlorate	33.7	97	0.4	320	384	12	30	9.5	11.4
66% Strontium perchlorate	42	41	3.2	272	295	16	34	6.5	7.0
70% Barium perchlorate	43	65	1.1	147	174	6	24	3.4	4.1

[a] Test vehicle, modified M112 charge case, 1.72 inches long.

[b] Remainder of composition consisted of aluminum powder.

TABLE 4

Luminosity Characteristics of Stoichiometric Calcium, Calcium Nitrate, and Calcium Perchlorate Compositions

Composition,[a] %	Calcium Content, %	Composition Weight, g	Peak, 10^6 candles	Time to Peak, msec	Integral Light 10^3 candlesec		Duration msec		Efficiency 10^3 candlesec/g	
					1/10 max	Total	1/10 max	Total	1/10 max	Total
Sea Level										
58% Calcium 42% Potassium perchlorate	54.0	14.0[b]	7.5	1.8	58	60	16	25	4.2	4.3
65% Calcium nitrate 35% Aluminum	15.9	18.0[b]	20	1.6	55	58	6	13	3.1	3.2
62% Calcium perchlorate 38% Aluminum	10.4	33.7[c]	54	0.6	291	314	12	24	8.6	9.3
100,000 Feet										
58% Calcium 42% Potassium perchlorate	54.0	14.0	16	0.6	145	152	24	35	10.0	10.8
65% Calcium nitrate 35% Aluminum	15.9	18.0	41	4.3	154	169	8	19	8.6	9.4
62% Calcium perchlorate 38% Aluminum	10.4	33.7	97	0.4	320	384	12	30	9.5	11.4

[a] Free and/or combined.

[b] Test vehicle: Magnesium Daisy cartridge with 0.075-inch-thick wall.

[c] Test vehicle: Modified M112 charge case, 2.72 inches long.

TABLE 5

Effect of Various Oxidants on Burning and Light Characteristics at Sea Level[a] of Binary and Ternary Mixtures Containing Calcium[b] Fuel

Composition, %					Free Metal Calcium Content in Excess of Stoichiometric,[c] %	Composition Weight, g	Peak Intensity, 10^6 candles	Time to Peak, msec	Integral Light ($^1/_{10}$ max), 10^3 candlesec	Duration ($^1/_{10}$ max), msec	Efficiency 10^3 candlesec/g
Calcium	Potassium Perchlorate	Sodium Perchlorate	Barium Nitrate	Sodium Nitrate							
75	25				18	11.7	11	2.7	98	15	8.4
80		20			19	13.3	10	4.9	108	18	8.1
80		10		10	21	12.3	10	3.9	107	19	8.7
80	20				26	11.7	9	4.4	101	20	8.6
85	15				34	10.8	9	5.5	119	25	11.0
70			30		39	15.5	9	15.5	72	17	4.7
90	10				42	12.4	7	8.0	62	20	5.0

[a] Test vehicle, Daisy cartridge, magnesium case, with 0.075-inch-thick wall.

[b] 85% fine metal content.

[c] $\frac{(\%\ \text{Calcium content} \times 0.85) - (\%\ \text{Calcium, stoichiometric})}{\%\ \text{Calcium, stoichiometric}}$

TABLE 6

Effect of Various Oxidants on Burning and Light Characteristics at 100,000 Feet[a] of Binary and Ternary Mixtures Containing Calcium[b] as Fuel

Composition, %						Percent Free Metal Calcium Content in Excess of Stoichiometric[c]	Composition Weight, g	Peak Intensity, 10^6 candles	Time to Peak, msec	Integral Light ($^1/_{10}$ max), 10^3 candlesec	Duration ($^1/_{10}$ max), msec	Efficiency, 10^3 candlesec, g
Calcium	Potassium Perchlorate	Sodium Perchlorate	Barium Nitrate	Sodium Nitrate	Calcium Nitrate							
75	25					18	11.7	10	8.9	265	45	22.7
80		20				19	13.5	12	16.1	364	48	27.3
80		10		10		21	12.3	12	15.1	343	57	27.9
80	20					26	11.7	9	14.8	271	47	23.2
85	15					34	10.8	10	9.8	307	49	28.4
70			30			39	15.5	13	19.7	214	40	13.8
90	10					42	12.4	9	11.6	263	57	21.2
70					30	45	12.8	19	1.7	239	30	18.7

[a] Test vehicle, Daisy cartridge, magnesium case, with 0.75-inch-thick wall.

[b] 85% free metal content.

[c] $\frac{(\%\ \text{Calcium content} \times 0.85) - (\%\ \text{Calcium, stoichiometric})}{\%\ \text{Calcium, stoichiometric}}$

TABLE 7

Luminosity Characteristics of Photoflash Compositions Containing Representative Alkaline Earth Nitrates

Composition[a]	Composition Weight, g	Peak Intensity, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 Candlesec		Duration, msec		Efficiency, 10^3 candlesec/g	
				$^1/_{10}$ max	Total	$^1/_{10}$ max	Total	$^1/_{10}$ max	Total
Sea Level									
35% Aluminum[b] 65% Calcium nitrate	18	20	1.6	55	58	6	13	3.1	3.2
30% Aluminum[c] 79% Strontium nitrate	43	30	1.8	183	201	18	32	4.3	4.7
26% Aluminum[c] 70% Barium nitrate	49	Too low to measure or nonignition of composition[d]							
100,000 Feet									
35% Aluminum[b] 65% Calcium nitrate	18	41	4.3	154	169	8	19	8.6	9.4
30% Aluminum[c] 70% Strontium nitrate	43	6	0.5	6	7	3	8	0.14	0.16
26% Aluminum 74% Barium nitrate	49	Light level too low to measure or composition did not ignite.[d]							

[a] Stoichiometric

[b] Magnesium Daisy cartridge

[c] Modified M112 Daisy cartridge

[d] Of 4 cartridges tested, 2 did not ignite, while the light output of the other 2 was too low to measure.

TABLE 8

Luminosity Characteristics of Photoflash Compositions Containing Representative Alkaline Earth Metal Nitrates and Perchlorates[a]

Composition[b]	Composition Weight, g	Peak Intensity, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec: 1/10 max	Integral Light, 10^3 candlesec: Total	Duration, msec: 1/10 max	Duration, msec: Total	Efficiency, 10^3 candlesec/g: 1/10 max	Efficiency, 10^3 candlesec/g: Total	Calculated Heat of Reaction 10^3 cal/g
Sea Level										
30% Aluminum, 70% Strontium nitrate	43	30	1.8	183	201	18	32	4.3	4.7	1.9
34% Aluminum, 66% Strontium perchlorate	42	64	1.6	327	343	10	15	7.8	8.2	2.5
26% Aluminum, 74% Barium nitrate	49	Light level too low to measure or composition did not ignite[c]								1.6
30% Aluminum, 70% Barium perchlorate	43	57	1.2	251	265	10	19	5.8	6.2	2.2
100,000 Feet										
30% Aluminum, 70% Strontium nitrate	43	6	0.5	6	7	3	8	0.14	0.16	
34% Aluminum, 66% Strontium perchlorate	42	41	3.2	272	295	16	34	6.5	7.0	
26% Aluminum, 74% Barium nitrate	49	Light level too low to measure or composition did not ignite[c]								
30% Aluminum, 70% Barium perchlorate	43	65	1.1	147	174	6	24	3.4	4.1	

[a] Test vehicle: Modified M117 charge case, 1.72 inches long.

[b] Stoichiometric.

[c] Of the 4 cartridges tested, 2 did not ignite while the light output of the other 2 was too low to measure.

TABLE 9

Use of Calcium Oxide and Calcium Fluoride as Chemical Additives to Fuel-Rich[a] Aluminum/Potassium Perchlorate Photoflash Compositions[b]

Composition, %: Aluminum	Composition, %: Potassium Perchlorate	Composition, %: Calcium Oxide	Composition, %: Calcium Fluoride	Composition Weight, g	Peak Intensity, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec: 1/10 max	Integral Light, 10^3 candlesec: Total	Duration, msec: 1/10 max	Duration, msec: Total	Efficiency, 10^3 candlesec/g: 1/10 max	Efficiency, 10^3 candlesec/g: Total
Sea Level												
39	61			42	41	1.7	226	246	11	16	5.4	5.9
36	55	9		35	35	0.7	179	192	10	14	5.1	5.5
31	49	20		34	35	1.4	171	179	9	16	5.0	5.3
27	43	30		28	2.6	1.8	12	13	20	29	0.4	0.5
36	55		9	44	37	1.3	235	249	13	20	5.3	5.7
31	49		20	35	28	1.8	110	114	9	13	3.2	3.3
27	43		30	Did not ignite								
100,000 Feet												
39	61			42	49	1.2	115	139	8	16	2.7	3.3
36	55	9		35	68	0.8	164	195	8	20	4.7	5.6
31	49	20		34	71	1.4	234	271	11	26	6.9	8.0
27	43	30		28	2.5	1.5	3.6	3.7	4	7	0.13	0.13
36	55		9	44	60	0.9	200	220	11	24	4.6	5.0
31	49		20	35	47	2.0	280	288	15	22	8.0	8.2
27	43		30	Did not ignite								

[a] 14% excess fuel.

[b] Test vehicle, M112 charge case reduced to 1.72-inch length.

TABLE 10

Luminosity Characteristics of Photoflash Compositions Consisting of High-Energy Fuels in Stoichiometric Combination with Potassium Perchlorate[a]

Fuel	Composition Weight, g	Peak, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec, ($^1/_{10}$ max)	Duration, msec		Efficiency, 10^3 candlesec/g	
					$^1/_{10}$ max	Total	Composition	Fuel
Sea Level								
34% Aluminum	42	41	1.2	147	9	14	3.5	10.3
41% Magnesium	35	18	1.2	142	16	24	4.1	10.0
57% Zirconium	58	38	0.7	92	7	14	1.6	2.8
41% Titanium	33	18	0.4	65	9	15	2.0	4.9
58% Calcium	23	12	1.2	75	13	16	3.3	5.7
17% Boron	31	0.5	23.0	18	68	89	0.6	3.5
29% Silicon	35		Did not ignite					
100,000 Feet								
34% Aluminum	42	49	1.3	103	7	14	2.5	7.3
41% Magnesium	35	16	0.5	10	1.2	33	0.3	0.7
57% Zirconium	58	65	0.7	92	3	11	1.6	2.8
41% Titanium	33	29	0.6	49	4	13	1.5	3.7
58% Calcium	23	26	0.5	176	21	29	7.7	13.3
17% Boron	31		No deflection					
29% Silicon	35		Did not ignite					

[a]Test vehicle, M112 charge case reduced to 1.72-inch length.

TABLE 11

Luminosity Characteristics of Photoflash Compositions Consisting of High-Energy Fuels in Combination with Potassium Perchlorate[a]

Fuel[b]	Composition Weight, g	Peak, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec, ($^1/_{10}$ max)	Duration, msec: $^1/_{10}$ max	Duration, msec: Total	Efficiency, 10^3 candlesec/g: Composition	Efficiency, 10^3 candlesec/g: Fuel
Sea Level								
39% Aluminum	42	41	1.7	226	11	16	5.4	13.8
47% Magnesium	35	20	2.3	189	17	25	5.4	11.5
65% Zirconium	62	55	0.9	278	11	23	4.5	6.9
47% Titanium	34	16	1.3	80	12	21	2.4	5.1
65% Calcium	22	13	1.7	115	15	19	4.8	7.4
20% Boron	30	2	14.3	51	55	92	1.7	8.5
33% Silicon	35		Did not ignite					
100,000 Feet								
39% Aluminum	42	49	1.2	115	8	16	2.7	6.9
47% Magnesium	35	18	0.8	11	1.3	35	0.3	0.6
65% Zirconium	62	80	0.8	149	4	15	2.3	3.5
47% Titanium	34	56	1.1	93	3	11	2.7	5.7
65% Calcium	22	21	3.4	367	30	35	13.9	21.4
20% Boron	30		No deflection					
33% Silicon	35		Did not ignite					

[a]Test vehicle and ingredients same as those used in Table 9 (p 21).

[b]Fuel content was 14% in excess of the stoichiometric amount.

TABLE 12

Luminosity Characteristics at Sea Level of Photoflash Compositions Consisting of High-Energy Fuels in Stoichiometric and Fuel-Rich Combinations with Potassium Perchlorate

Fuel	Type of Composition[a]	Peak, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec, ($^1/_{10}$ max)	Duration, msec: $^1/_{10}$ max	Duration, msec: Total	Efficiency, 10^3 candlesec/g Fuel	% Increase in Efficiency
Aluminum	S	41	1.2	147	9	14	10.3	35
	X	41	1.7	226	11	16	13.8	
Magnesium	S	18	1.2	142	16	24	10.0	15
	X	20	2.3	189	17	25	11.5	
Zirconium	S	38	0.7	92	7	14	2.8	147
	X	55	0.9	278	11	23	6.9	
Titanium	S	18	0.4	65	9	15	4.9	4
	X	16	1.3	80	12	21	5.1	
Calcium	S	12	1.2	75	13	16	5.7	30
	X	13	1.7	115	15	19	7.4	
Boron	S	0.5	23.0	18	68	89	3.5	85
	X	2	14.3	51	55	92	8.5	
Silicon	S			Did not ignite				
	X			Did not ignite				

[a] S = Stoichiometric, X = 14% excess fuel.

TABLE 13

Luminosity Characteristics at a Simulated 100,000 Feet of Photoflash Compositions Consisting of High-Energy Fuels in Stoichiometric and Fuel-Rich Combinations with Potassium Perchlorate

Fuel	Type of Composition[a]	Peak, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec, ($^1/_{10}$ max)	Duration, msec $^1/_{10}$ max	Duration, msec Total	Efficiency, 10^3 candlesec/g Fuel	% Increase in Efficiency[b]
Aluminum	S	49	1.3	103	7	14	7.3	(5)
	X	49	1.2	115	8	16	6.9	
Magnesium	S	16	0.5	10	1.2	33	0.7	(14)
	X	18	0.8	11	1.3	35	0.6	
Zirconium	S	65	0.7	92	3	11	2.8	25
	X	80	0.8	149	4	15	3.5	
Titanium	S	29	0.6	49	4	13	3.7	54
	X	56	1.1	93	3	11	5.7	
Calcium	S	26	0.5	176	21	29	13.3	61
	X	21	3.4	307	30	35	21.4	
Boron	S	Light level too low to measure						
	X	Light level too low to measure						
	S	Did not ignite						
	X	Did not ignite						

[a] S = Stoichiometric, X = 14% excess fuel.

[b] Figures in parentheses represent percent decrease in efficiency.

TABLE 14

Evaluation of Calcium, Calcium Hydride, and Calcium-Containing Alloys at Sea Level and 100,000 Feet[a]

Composition	Composition Weight, g	Free Calcium,[b] %	Peak Intensity, 10^6 candles	Time to Peak, msec	Integral Light ($^1/_{10}$ max), 10^3 candlesec	Average Intensity ($^1/_{10}$ max) 10^6 candles $\left(\frac{\text{Integral Light}}{\text{Duration}}\right)$	Duration ($^1/_{10}$ max), msec	Efficiency 10^3 candlesec/g: Composition	Efficiency 10^3 candlesec/g: Fuel	Efficiency 10^3 candlesec/g: Free Metal Calcium
Sea Level										
80% Calcium-aluminum alloy 20% Potassium perchlorate	26	40	17	7.7	259	9	28	10.0	12.5	24.9
65% Calcium 35% Potassium perchlorate	22	55	13	1.6	106	7	15	4.8	7.4	8.7
65% Calcium hydride 35% Potassium perchlorate	32	58	2	5.5	26	1	23	0.8	1.2	1.4
80% Calcium-magnesium alloy 20% Potassium perchlorate	31.5	59	18	7.0	272	9	29	8.6	10.7	14.6
80% Calcium 20% Potassium perchlorate	21	68	19	5.5	225	11	22	10.7	13.4	15.8
100,000 Feet										
80% Calcium-aluminum alloy 20% Potassium perchlorate	26	40	27	16.4	682	15	45	26.2	32.8	65.5
65% Calcium 35% Potassium perchlorate	22	55	21	3.4	307	10	30	13.9	21.4	25.2
65% Calcium hydride 35% Potassium perchlorate	32	58	2	14.8	26	0.8	33	0.8	1.2	1.4
80% Calcium-magnesium alloy 20% Potassium perchlorate	31.5	59	23	21.3	859	11	75	27.2	34.0	46.2
80% Calcium 20% Potassium perchlorate	21	68	28	17.1	721	17	43	34.3	43.0	50.5

[a] Test vehicle: M112 charge case reduced to 1.72-inch length.

[b] Determined by multiplying the percent of calcium metal, alloy, or compound used in the mixture by the free metal or reactive calcium content found by chemical analysis. The analyses of the free metal content were as follows: calcium-aluminum alloy, 50% calcium, 50% aluminum; calcium-magnesium alloy, 75% calcium, 22% magnesium; calcium metal, 85% calcium; calcium hydride, 89% calcium.

TABLE 15

Effect of Aluminum as a Partial Replacement for Calcium in a Fuel-Rich Calcium/Potassium Perchlorate[a] Composition

Composition	Composition Weight, g	Peak Intensity, 10^6 candles	Time to Peak, msec	Integral Light ($^1/_{10}$ max), 10^3 candlesec	Duration ($^1/_{10}$ max), msec	Efficiency, 10^3 candlesec/g
Sea Level						
80% Calcium 20% Sodium perchlorate	26	22	5.2	354	27	13.7
55% Calcium 10% Aluminum 35% Sodium perchlorate	34	24	1.3	191	19	6.5
100,000 Feet						
80% Calcium 20% Sodium perchlorate	26	32	18.8	1178	62	45.7
55% Calcium[b] 10% Aluminum 35% Sodium perchlorate	34	36	0.8	618	42	18.2

[a] Test vehicle: M112 charge case reduced to 2.3-inch length.

[b] 10 parts by weight of aluminum is equivalent to 25 parts by weight of calcium in reacting with sodium perchlorate.

TABLE 16

Percentage Compositions of Experimental Mixtures Subjected to Impact and Friction Tests

Composition (PFP Number)

Ingredients	664	679	682	690	946	680	677	685	687	728	688	726	618
Aluminum	39	43	46	34	38	30	30	30	36	27	36	27	
Calcium													58
Magnesium													
Zirconium													
Titanium													
Boron													
Silicon													
Calcium-magnesium													
Calcium-aluminum													
Calcium hydride													
Potassium perchlorate	61								55	43	55	43	42
Sodium perchlorate		57											
Lithium perchlorate			54										
Calcium perchlorate					62								
Strontium perchlorate				66									
Barium perchlorate						70							
Sodium nitrate													
Barium nitrate							70						
Strontium nitrate								70					
Calcium oxide									9	30			
Calcium fluoride											9	30	
Picatinny Arsenal Impact Test, inches	34	19	19	15	14	15	27	32	27	35	25	35	15
Friction Pendulum Steel shoe	D	B	D	NA	NA	D	NA	NA	D	B	D	NA	D
Fibre shoe	NA	NA	Sp	–	–	NA	–	–	NA	NA	NA	–	NA

Ingredients	665	620	681	689	686	667	668	669	670	675	672	699	738	693
Aluminum														
Calcium	65	75	51	80	75									
Magnesium						47								
Zirconium							57	65						
Titanium									47					
Boron										20				
Silicon											33			
Calcium-magnesium												80		
Calcium-aluminum													80	
Calcium hydride														65
Potassium perchlorate	35	25				53	43	35	53	80	67	20	20	35
Sodium perchlorate			49											
Lithium perchlorate														
Calcium perchlorate														
Strontium perchlorate														
Barium perchlorate														
Sodium nitrate				20										
Barium nitrate														
Strontium nitrate					25									
Calcium oxide														
Calcium fluoride														
Picatinny Arsenal Impact Test, inches	15	15	27	15	13	24	19	21	22	8	40+	16	25	15
Friction Pendulum Steel shoe	D	D	D	B	B	B	D	D	B	B	NA	D	B	D
Fibre shoe	NA	NA	NA	B	NA	NA	Sp	B	B	B	–	D	B	D

Code: B = Burned
D = Detonated
NA = No action
Sp = Sparked

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Seymour Lopatin

Technical Report FRL–TR–29, October 1961, 31 pp, tables. DA Proj 504–01–027, Ord Proj TS5–5407. Unclassified report.

Calcium/magnesium and calcium/aluminum alloys are satisfactory substitutes for calcium metal powder as highly efficient fuels for high-altitude photoflash items. When tested under pressures simulating a 100,000-foot altitude, these alloys had much greater light output than at sea level. This phenomenon can also be obtained with compositions containing calcium salts which are oxidants (calcium nitrate, calcium perchlorate) or additives

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Picatinny Arsenal, Dover, N. J.
SEA-LEVEL AND HIGH-ALTITUDE PERFORMANCE OF EXPERIMENTAL PHOTOFLASH COMPOSITIONS
Seymour Lopatin

Technical Report FRL–TR–29, October 1961, 31 pp, tables. DA Proj 504–01–027, Ord Proj TS5–5407. Unclassified report.

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(over)

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V. Title: Photoflash compositions

UNITERMS

Sea level
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Performance
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Test results indicated that calcium—as a metal powder, alloy, or salt—is necessary for the production of superior high-altitude flashes.

The alkaline earth perchlorates were found to be better oxidants than the alkali metal perchlorates. Of the alkaline perchlorates evaluated (calcium, strontium, and barium), the calcium compound was optimum at both sea level and high altitude. Sodium perchlorate was optimum at high altitude among the alkali perchlorates investigated (sodium potassium, and lithium).

Substituting alkaline earth perchlorates for their respective nitrates considerably improved light output at both sea level and high altitude. Substituting barium perchlorate for barium nitrate also improved the ignitability of the composition.

Of the high-energy fuels evaluated (aluminum, magnesium, zirconium, titanium, calcium, boron, and silicon), aluminum and magnesium were most efficient at sea level, while calcium was most efficient at 100,000 feet.

UNITERMS

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Calcium perchlorate
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Calcium fluoride
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